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Universalization of access to modern energy services in Tibetan rural households—Renewable energy's exploitation, utilization, and policy analysis

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ABSTRACT

There are still more than 30% of the Tibetan administrative villages without power, and about 40% farmers there are suffering from a serious shortage of firewood. Tibet is abundant in the deposits of hydropower, geothermal, and solar energy. The practical ways to solve the universal service of Tibetan rural energy are researched in the paper. We find that there are two main objectives of the universal access to energy in Tibetan rural areas. One is to meet the demand of electricity consumption and daily energy consumption of the farmers and herdsmen without power, initially solve energy poverty, realize the equitable access to energy, and ensure the early access to modern civilization. The other is to guarantee the provision of energy required in Tibet's rural economic development and urbanization. Their accomplishment depends on the responsibilities' definition and implementation in the universal service of energy by the central and local governments, and on the establishment of a universal service mechanism of energy. The conflict between the need of energy development in the agricultural and pastoral areas of Tibet and its insufficient financial resources cannot be solved without the support and assistance from the central government and other developed provinces in China.

Contents

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1. Introduction

Located in the Southwestern border of China, Tibet Autonomous Region (TAR) has an average elevation of more than 4000 m, with the complex and varied topographic and geological conditions, fragile ecology, and adverse weather condition. In 2009, the Tibetan total population is 2.9003 million, including a rural population of 2.21 million, which counts for 76.2% of the total. The recent years have witnessed rapid economic and social development in Tibet, with its GDP having maintained an average annual growth rate of 10 percent. GDP of 2009 is 44.136 billion yuan, with the respective proportion of the added value of the first, second and tertiary industry – 14.5%, 30.9%, and 54.6%. The fiscal revenue of 2009 is 3.037 billion yuan, accounting for less than one in a thousand of China's fiscal revenue. The per capita net income of the farmers and herdsmen is 3532 yuan, far below the national average [1].

The rapid economic growth leads to the increasing demand for energy. However, since the industry still forms a very small proportion of Tibet's economy, and the industrial foundation is relatively backward, the lag of energy infrastructure has become a bottleneck holding back the economic development of Tibet [2]. Chinese government has always been highly concerned about the energy and electricity supply in Tibet. To speed up the improvement of the living and production conditions of farmers and herdsmen in TAR, and to urge the balanced economic and social development, since 2006, State Grid Corporation has been actively promoting the "Power for Every Household" Project in the farming and pastoral areas, in the hope of solving the electricity problem of rural residents without power supply through the grid's maximum extension. The accumulated investment of the project is 2.92 billion yuan, and it has solved the power problem of 172,000 households, namely, that of about 763,000 people. However, by the end of 2010, in TAR, the administrative villages with power supply only account for 69% of all, with over 500,000 households of farmers and herdsmen without power supply, and drinking water problems still exist in some areas [3]. Moreover, about 40% households in Tibet are facing a serious shortage of firewood. The farmers and herdsmen mainly rely on dung, firewood and other biomass, supplemented with electric energy and solar energy. This is due to the fact that modern energy services are associated with high initial cost of device and high connection and operating costs compared to cheaply available biofuels (firewood, wood chips/sticks, agro waste and dung cakes) [4]. The demographic and geographic characteristic is the main cause of low rate of grid-based electricity [5]. Provision of modern energy services for cooking (with gaseous fuels) and lighting (with electricity) is an essential component of any policy aiming to address health, education or welfare issues. Secure, adequate, low-cost energy of quality and convenience is core to the delivery of these services. To achieve millennium development goals (MDGs) it is important to provide modern energy services to all. Combining renewable energy technology and traditional energy can provide various energy solutions for the specific conditions and needs of Tibet [6–9]. Solar, wind, micro-hydro and biological energy are all effective methods to product low-cost, efficient energy [10,11]. Hence, to provide all households with modern energy services one needs to be open to new mechanisms and look for innovative solutions.

However, previous studies mainly focus on the technology development and research of renewable energy or one kind of renewable resources [12–21], with inadequate attention paid to how to use renewable energy to achieve the goal of the universal service of energy for Tibetan farmers and herdsmen, and to the policies and mechanisms for implementation. The research objectives of the paper are: (1) studying the energy consumption of Tibetan farmers and herdsmen, (2) gaining a clear idea of the distribution and utilization of Tibet's renewable energy resources, (3) analyzing the way of using renewable energy to replace traditional energy sources in order to achieve universal services, and (4) proposing the policy framework and mechanism for implementation.

2. Implication of energy service in Tibet

2.1. Production of farming and pastoral areas

Tibet is called "the third pole of the earth". Because of the unfavorable natural conditions, the various ethnic minority groups there have formed their unique ways of life and production. The fundamental characteristics are as follows: the households mainly focus on the natural economy, maintain the simple reproduction and live a simple life at the mercy of the forces of nature; the farming and pastoral areas of Tibet are sparsely populated, and the farmers are sparsely scattered, with less than 3 people per square kilometer, which makes Tibet the region with the smallest population density; because of the scattered living, the interaction between people is very difficult, and it is very hard to establish and provide public facilities and public services for people's exchanges like other parts in Chinese mainland; in such a relatively closed area, religious belief becomes the important spiritual and living support for farmers and herdsmen.

At present, there is no fundamental change in the mode of production based on the natural economy in the farming and pastoral areas of Tibet. The lack of the necessary conditions for marketization and industrialization in such areas exists, and the biggest challenge is the inadequate supply of energy and other basic conditions and public services.

2.2. Necessities for subsistence

As a matter of course, food and housing are the most basic needs of living for the farmers and herdsmen, and they are the individual needs that can be obtained through market purchase. However, in the farming and pastoral areas of Tibet, meeting the needs of food and housing is inseparable from the energy-related services provided by the government.

Food is the most basic need of human beings. Living in the specific environment, the farmers and herdsmen in Tibet have formed the diet habit of eating beef and mutton as the main food. One important matter related to food is energy supply. At present, cow dung is basically used as the main fuel in the farming and pastoral areas of Tibet and some generating facilities for wind power or solar energy are only established in the places given support and subsidies by public finances. This kind of energy consumption habit is not only primitive, but also adverse for the protection of the already fragile pastures of the Tibetan Plateau. Without cow dung and other organic fertilizers, the biomass on pastures will be reduced, and then increasing pressures will be given to the already overloaded pastures [22]. Therefore, as for the demand of food, the farming

Table 1
Rural electricity consumption in Tibet.

	Year				
	2000	2001	2003	2006	2007
Rural electricity consumption/10,000 kWh	3392	3117	4305	6354	5553
Electric energy production in Tibet/10,000 kWh	66,075	69,690	101,600	151,514	169,072
Hydropower generation/10,000 kWh	55,350	58,958	92,083	137,901	156,164
Proportion of rural electricity consumption in electric energy production (%)	5.1	4.5	4.2	4.2	3.3
Proportion of hydropower generation in electric energy production (%)	83.8	84.6	90.6	91.0	92.4

Source: Tibet Power Company (2008).

and pastoral areas in Tibet need energy system to support. Generally speaking, energy resources are always viewed and treated as private goods. But in Tibet, because the farming and pastoral areas are sparsely populated, and the purchasing power there is low, it is very hard to solve energy supply through the private supply in market mechanism, and the measures taken by the government are needed.

Because of the cold climate, the heating period in most farming and pastoral areas is more than 9 months in the whole year, and in some places, heating is needed for 12 months. Without a better energy system, the residents will face great difficulty in meeting their basic living standard.

2.3. Basis of the trading of farm and stockbreeding products

The production of Tibetan farmers and herdsmen mainly relies on natural production conditions, so it is hard to lead to many surpluses of farm and animal husbandry products. The transition from natural economy to market economy cannot do without the most fundamental public service systems, such as transportation facilities, information conditions, and financial services. The reality of Tibet shows that these basic conditions are rather inadequate now. Although "To Every Village" project and "Network Program" (access to broadcasting, television, highway, power) project are implemented, the lack of electric power, the message block, and the unsmooth information channel are still the phenomena that restrict the development of the farming and pastoral areas, which cannot be ignored. For example, Qiangtang town, Nagarze County, only over 200 km from Lhasa, but one of the towns with the highest elevation in Tibet, receives newspapers at least 10 days later than in Lhasa. The lack of infrastructure and public products always leads to the failure of exchange by the rural and pastoral residents in Tibet even if they have surplus products. As the infrastructure and public service system which are adaptable to the production and life of farmers and herdsmen are not established, the farmers and herdsmen's expenditure is added, and the rate of capital accumulation is decreased. At the same time, the rural financial institutions in Tibet are few, and the line of credit is low, so the chances are very small for the farmers and herdsmen who want to increase and improve the basic conditions for production and capital goods through financing. As a result, even if the rural and pastoral residents in Tibet can make some income through the exchange of commodities, and then form surplus funds on hand, it is very hard to transform them into productive capital.

2.4. Social implications of energy use

Use of traditional fuels for cooking with the attendant pollution and the opportunity cost of gathering them imposes a heavy burden of back-breaking and time-consuming job on people particularly women and young girls. Poor households tend to spend more time in collecting these fuels than those from higher-income groups. The need to gather fuels may deprive the young girls from schooling. This "hard earned" energy is used very inefficiently, converting only about 15% of the total into useful energy [23]. Use of such inefficient and polluting fuels, over time, increases the risks of eye infections and respiratory diseases and it affects the health of women and the girls more adversely, as they spend more time indoors and are primarily responsible for cooking. In the farming and pastoral areas of Tibet, the average time for a woman to collect biomass is 1.5 h, and the time of using the traditional biomass to cook is 2.5 h [4].

Table 2
Major durable goods owned by every 100 rural households.

	Year		
	2000	2005	2007
Washing machine (set)	2.3	7.0	8.6
Motorcycle (set)	0.2	14.7	33.4
Black and white television (set)	4.8	2.0	1.4
Color television (set)	9.0	47.4	53.9
Refrigerator (set)	0.4	4.4	10.1

Source: Statistical Yearbook of Tibet (2008).

3. The status quo and features of rural energy consumption in Tibet

3.1. Relatively low consumption of conventional energy resources

Conventional energy resources mainly include coal, oil products, natural gas, and electric power. Tibet's per capita consumption of conventional energy is only about 300 kg of standard coal, which is only 1/4 of the national average. In the terminal energy consumption structure, the proportions of the conventional energy are as follows: oil products accounting for 46%, electric power 41%, liquefied petroleum gas 5%, and coal 8%. Since Tibet is lack of the conventional energy resources, such as coal, oil products, and natural gas, the supply mainly relies on the input from other provinces, which leads to the high cost and the little rural consumption. In 2007, the rural population accounts for about 85% of the total, but the rural electricity consumption only accounts for 3.3% of the gross generation in Tibet, with more than 90% power consumed by the urban residents. The rural areas mainly depend on hydroelectric power, shown in Table 1.

Because of the poor living conditions in Tibetan rural areas, the penetration rate of major energy-consuming household appliances is very low, and the electricity consumption in rural areas is low, as well (shown in Table 2). It is not difficult to understand that for the per capita power consumption in rural areas, Tibet is less than 1/3 of the national average, and there is a very large gap between Tibet and other western provinces and autonomous regions (shown in Table 3).

3.2. Too high proportion of biomass energy consumption

In Tibet, the fuel-wood energy is mainly consumed by farmers and herdsmen. The people facing a serious shortage of firewood account for about 40% of the total households in the farming and pastoral areas. In most rural areas in Tibet, the main energy

Table 3
Electricity consumption of rural residents in China in 2006 (unit: Kwh).

Region	Household consumption of every family	Household consumption per capita
Nationwide	388.2	103.2
Tibet	172.3	30.9
Sichuan	358.8	102.9
Guizhou	286.4	69.3
Yunnan	196.0	48.2
Shaanxi	264.0	66.7
Gansu	218.6	48.9
Qinghai	223.5	48.5
Ningxia	267.4	60.3
Xinjiang	217.7	49.3

Source: The Second Agriculture Census by the State Council (2008).

resources are dung, firewood and other biomass, supplemented with electric energy and solar power, with the consumption of fuel-wood energy accounting for about 70% in the overall energy consumption. According to a survey, in rural energy consumption, dung accounts for 52.93%, firewood 36.78%, straw 10.17%, and other energy (oil, electric energy, solar power) only 0.12% [24]. In Tibet, the sequence of proportions of major cooking energy resources in every rural household is: firewood, dung, gas (natural gas), solar power, coal, biogas, and electric energy. It is clearly shown in Table 4 that on the energy use for cooking, there is a remarkable gap between the rural households in Tibet and that in western regions and the whole country, and the difference is mainly manifested in the use of coal and dung. Since Tibet is lack of coal and the transportation cost is high, the use of coal is very limited. Besides, because of the low cost of local rural cattle and sheep manure, and the easy access to them, nearly 50% of the households use them as the cooking energy.

4. Distribution and utilization status of renewable energy resources in Tibet

4.1. Hydropower

The exploitable capacity of the hydroelectric resources in Tibet is 0.116 billion kW, and the annual energy production is over 600 billion kWh. The theoretical reserves and the developable resources both make up 30% of China's total, of which the developable resources rank the second in the nation, next only to Sichuan.

The theoretical reserves of Tibet's hydropower resources are mainly in Southeast Tibet, constituting about 60% of all the theoretical reserves of Tibet's hydropower resources. "Sanjiang Rivers" (Jinsha River, Lancang River, and Nujiang River) in eastern Tibet makes up 15% of the theoretical reserves of Tibet's hydropower resources, southern Tibet 24%. The Northern Tibet Plateau accounts for 2/3 of the area in Tibet, but the developable hydropower resources only make up 1%. Yarlung Zangbo River Valley constitutes 87.2% of the theoretical reserves of Tibet's hydropower resources [25].

In Tibet where the conventional energy resources are scarce, the exploration and utilization of hydropower resource plays a significant role in the energy industry of the plateau, and the exploration of Tibet. Because of the restriction of the natural environment, the miniaturization of hydropower generation is the prominent feature. So far, the abundant hydroelectric power resources in Tibet have not been fully developed and utilized.

4.2. Solar energy

Tibet is one of the places in the world with the most extensive deposits of solar energy resource. Table 5 shows that there are 1750–3300 h of sunshine annually and there are on average 275–330 days with more than 6 h of sunshine per day in a year. The radiant intensity is high, with the total solar radiation of 7000 MJ/m^2. Its geographical distribution increases from east to west, with the most in the west, the second in Dingri on the north slope of Mount Everest, reducing gradually to the southeast, complementary with hydropower. The total amount of solar radiation changes with seasons, with the most in spring and summer, and the least in autumn and winter. However, because of the limited types of solar-related products, the solar energy in Tibet is only used for illumination and boiling water, which is on the low level of utilization, far from satisfying people's energy needs.

4.3. Wind power

The total reserve of wind energy resource in Tibet is about 7730 kW. There are two zones of strong wind in Tibet – one is the area from North Tibet to Ngari, lying roughly on Heihe river road, and the other one is the east section of the valley area between the Himalaya Mountains and Gangdise Mountains. However, because of the topography and the elevation, there is almost no place with the annual average wind speed over 5.0 W/m^2 in Tibet. The areas where the wind power resource can be utilized in Tibet are mainly distributed in the farming and pastoral areas sparsely populated, with the poor transportation services and comparatively backward economy. It is very difficult to build wind energy farms there, and the operation and maintenance of wind power generators are quite hard even if the farms are established. This kind of natural condition causes the little feasibility of developing large-scale wind generating sets, and it has a brighter future to popularize small-sized wind power generators and utilize them with other resources. Because of the complex terrain in Tibet and the lack of station observation data, the detailed investigation of the actual distribution of wind power and its utility value should be conducted.

4.4. Geothermal energy

The geothermal energy resource in Tibet is characterized by wide distribution, high temperature and abundant deposits. The resources of middle and low temperature are mainly distributed in southern Tibet, western Tibet and northern Tibet. The exploration, development and utilization of geothermal energy resource in Tibet were started in 1970s, and great progresses have been made in geothermal power generation through 30 years' effort. In Tibet, the geothermal energy of middle and low temperature is used for exploration, for example, Yangbajing Geothermal Field, whose generation potential is 34 MW and which can be exploited for 30 years. The installed gross capacity of geothermal power

Table 4
Composition of rural residents according to the major use of cooking energy (unit: %).

Region	Firewood	Coal	Gas or natural gas	Biogas	Electric energy	Other energy resources
Tibet	51.9	0.21	1.7	0.05	0.04	46.1
Western regions	56.9	38.4	3.8	0.7	0.2	0.0
Nationwide	60.2	26.1	11.9	0.7	0.8	0.3

Source: The Second Agriculture Census by the State Council (2008).

Table 5
Solar energy resource distribution in Tibet.

Region	Average annual hours of sunshine (h)	Average annual radiation (MJ m^{-2})	Area (km^2)	Average altitude (m)
Lhasa	3000	7500–8000	29520	3700
Shannan	2900	7000–8000	78,900	3600
Qamdo	2180–2700	6200–6500	108,700	3500
Shigatse	2600–2860	700–8000	417,000	4000
Nagqu	2800–2860	7500–8000	420,000	4500
Nyingchi	1750–2010	4590	117,000	3000
Ngari	3300	7000–8000	305,000	4500

Source: Tibet Power Company (2008).

stations is 25.18 MW, accounting for 15% of Lhasa's installed capacity of power network, and it mainly supplies electric power for Central Tibet (Lhasa, Shannan, Shigatse, and Nagqu). After the development of geothermal resources in Yangbajing, Tibet exploited the geothermal fields in Yangyixiang, Nagqu, and Langjiu in succession and built three fairly standard geothermal power stations with the installed gross capacity of 28.18 MW.

Tibet's geothermal application occupies the fires place in China. Nevertheless, since a few matters are ignored in the exploitation of geothermal power fields, such as the scientific research, supervision, environmental protection and sustainable use, the utilization rate of geothermal resources is only 6%.

4.5. Biogas

In 1970s, some experts and scholars started to do the exploratory study on biogas in Duiongdeqing County in Lhasa and Shannan. In 2003, Tibet took lead in the experiment on household energy mode of biogas in Shigatse, and the result shows that the application in low temperature has been realized in technology, which changes the traditional mode of biomass energy utilization.

In view of the high altitude, low temperature, and large temperature differences, scientific researchers drew lessons from the mainland experience and technology, successfully built biogas generating pits adaptable to Tibet's climate characteristics, and provided heating and heat preservation for the pits by using the abundant solar energy, to ensure the use of biogas in winter. Up to 2006, 1180 biogas generating pits have been established in Shigatse, Shannan, Nyingchi, Qamdo, and the outskirt of Lhasa, with the average total pit volume of 11800 m^3. The problem of energy use in 2950 people's daily life has been solved, and the ecological engineering system of biogas–solar energy–cultivation–planting–toilets was formed gradually. However, farmers' biogas building lacked related financial support because of the restriction of local economy. It needs 2000 yuan to build a biogas pit of 8 m^3, and some rural households find difficulty in raising funds to build the pit. Most of the farmers do not have the popular science related to biogas generating pits, which leads to the lack of follow-up management on the already built pits; as a result, the comprehensive utilization ratio of biogas is very low. A few rural households even want to give up the use of biogas generating pits.

5. Exploitation and utilization status of renewable energy and challenges ahead in Tibet

5.1. Utilization of renewable energy in Tibet

Since 1980s, the energy construction of Tibetan rural areas has mainly focused on the promotion of solar power, and "Sunshine Plan", "Light of Science", "Electricity Plan in Ngari", and the project of "making every township have access to electricity" have been implemented in succession. In 2004, over 400 solar photovoltaic power stations were built, with the total capacity of 9000 kW and the total installed capacity ranks first in China. The implementation of these projects plays an important role in the electricity consumption of the farmers and herdsmen without power in Tibet. In 1990s, the "Ride Wind Program" was implemented, various types of wind power generators were successively introduced to Nagqu, Shigatse, Shannan, and Ngari, and other areas in Tibet, and a number of model towns and villages in terms of wind power were established, which make people see the hope and prospect of wind power and solar energy in solving the energy supply in the farming and pastoral areas of Tibet.

There are a huge base number of the rural households without power in Tibet which are widely distributed. The rural power grid is relatively backward and renewable energy resources play an irreplaceable role in rural universal services of energy. In 2005, more than 220,000 households in Tibet were distributed in about 3500 natural villages, and the residential areas without power are widely distributed (see Table 6).

The lighting condition of rural areas in Tibet in the year of 2005 shows that 51.2% of the towns, 30.2% of the villages and 28.4% of the rural households utilized renewable energy resources, such as solar energy, small hydropower and wind power, to solve the electricity problems (see Table 7). Consequently, besides extending the network, it is one of the best ways to make a full use of local

Table 6
Power rate of rural areas in the Tar in 2005 (unit: %).

Region	Town	Village	Household
Lhasa	98.2	75.5	86.8
Shannan	96.3	58.3	68.3
Shigatse	55.7	40.7	49.4
Nagqu	77.2	27.8	35.9
Nyingchi	61.8	14.6	64.6
Qamdo	59.4	29.9	43.2
Ngari	94.4	61.3	63.9
Total	71.0	41.0	59.6

Source: Tibet Power Company (2008).
Note. The utilization of small hydropower stations and illumination by solar power are included.

Table 7
Power supply by small hydropower and solar energy power generating (off-net) in Tibetan rural areas in 2005.

Region	Town	Village	Households
Lhasa	8	24	2565
Shannan	53	242	14,045
Shigatse	69	421	27,600
Nagqu	83	326	27,373
Nyingchi	28	349	15,803
Qamdo	76	346	33,119
Ngari	33	84	14,690
Total	350	1792	155,352
Proportion in all the towns, villages, and households respectively	51.20%	30.20%	28.40%

Source: Based on the data of Tibet Power Company.

renewable resources in light of local conditions for solving the electricity problem of the households without power in Tibet.

On the utilization of solar energy, it is very common for urban residents to use solar water heaters and solar cookers. In comparison, in vast farming and pastoral areas which are relatively sparsely populated, rural households mainly use solar cookers, but the lack of maintenance knowledge causes a high failure rate of the already installed solar water heaters, and the restricted promotion and demonstration. At the end of 2009, there were totally 330,000 solar cookers promoted, one million square meters of passive solar houses, sunshine greenhouses, and solar water heaters, over 100,000 sets of solar photovoltaic household system, and biogas generating pits invested and built for 115,000 households in Tibet.

5.2. Main challenges facing the development and utilization of renewable energy in Tibet

To solve the electricity problem of the farmers and herdsmen in the villages without power, State Grid Corporation, maximizing the extension of network, invested 2.92 billion yuan in total, and solved the electricity problem of 172,000 rural households, investing 17,200 yuan to every household on average. Based on the conditions of the farming and pastoral areas of Tibet, it is very hard on technology and unreasonable on economy to solve the power supply to tens of thousands households without power by extending network. The feasible way is to make a full use of the renewable energy; however, the practical difficulties are following.

5.2.1. High cost of renewable energy's development, utilization and operation

With a low level of urbanization in Tibet, and the sparsely populated farmers and herdsmen, the planning and construction cost of energy infrastructure is very high, and it is difficult to complete by only relying on the local government finance.

The cost of renewable energy's development, utilization and operation is very high. For example, the single capital investment of photovoltaic system or wind/solar complementary system, and the storage battery replacement cost are huge. According to the market price, in power stations used in villages, the construction cost of photovoltaic system is 120,000 yuan/kW, and 95,000 yuan/kW for wind power system; while in the household systems, 95,000 yuan/kW is needed for photovoltaic part, and 50,000 yuan/kW for wind power part. On average, 3–5 years after the station's operation, storage batteries should be replaced, and the replacement cost accounts for about 60% of the total investment Being restricted by the local economy, the rural households lack related financial support on the construction of biogas generating pits. It needs 2000 yuan to build a biogas generating pit of $8\,m^3$, and collecting the funds for biogas generating pits is difficult to some rural households. Although the technology of developing small hydropower is mature, and the economic cost is relatively low, with the increasing amount of cumulative exploitation, development costs will become a major constraint.

5.2.2. Imperfect energy service system

The energy service system is still imperfect. In Tibet, there is not a mature and corresponding maintenance service network in standard operation. Solar-related products are expensive, and how to ensure that the facilities in every household are of high quality, high reliability and with a reasonable service price are the elements that most users are concerned about. Solar energy industry is investment-intensive and technology-intensive, and there is a shortage of technical and service personnel, which result in the maintenance service backwardness of solar-related products. What is more, since there has not been a scientific testing system, the uneven quality of solar products and the big difference in configuration for products with the same specification create difficulties to farmers and herdsmen in choosing and purchasing solar-related products. At the same time, it is a big challenge to train the sparsely populated residents to properly use the equipment, who have relatively low literacy and weak technological capability. It is of great importance to provide basic training for operating personnel and farmers and herdsmen consuming electricity, and it is an arduous challenge, as well. Most farmers lack the scientific knowledge related to biogas generating pits, and the follow-up management to the already built pits lags behind, which leads to the low rate of multipurpose utilization on biogas. Some rural households even want to give up the use of biogas generating pits.

5.3. Realistic options

Based on the analysis of practice and theory, making a full use of the renewable energy is the feasible way to realize the universalization of access to energy in Tibetan rural households, and the sustainable development.

Nowadays, the population growth, rapid regional economic and social development and the increase in energy demand bring about new challenges for Tibet's ecological protection and conservation of biological diversity. As a result, from the perspective of protecting Tibet's ecological environment and sustainable development, it is imperative for Tibet to implement the strategy of alternatives to fuel-wood energy. The specific methods include: introducing the new technologies and processes of energy development and utilization which are mature at home and abroad, forming a relatively complete system for the large-scale production, selling and energy service, ensuring the wide application and utilization of Tibet's solar energy, hydropower, and biogas, changing the traditional inefficient utilization patterns of biomass energy, gradually increasing the proportion of renewable energy in energy consumption structure, and progressively realizing the transformation from mainly relying on traditional biomass energy to renewable energy-based consumption structure. The Planning Outline for Alternatives to Fuel-wood Energy in TAR points out that by selecting 3–5 counties of different types in the first batch to carry out the demonstration pilot projects of alternatives to fuel-wood energy, the substitution rate of traditional energy sources comes to 60%.

6. Policy recommendation and innovation of investment mechanism

6.1. Policy recommendation

Governmental responsibilities should be specified, and the mechanism for universal services of energy should be established. The government plays a very important role in universal services of energy. Universal services of energy are one of the important components of public services, and the government should play a leading role in guaranteeing the basic living energy for the public needs. First, it should be stipulated that government departments are the subjects of liabilities to provide universal services of energy. Second, the responsibilities of the central government and local governments for universal services of energy should be specified according to the division of powers and responsibilities. The universal services of energy in Tibet reflect the overall national interests and local interests, so the central government and the government of Tibet should share the responsibilities together. Because of the special financial authority and financial resources of Tibet, at present, the TAR can only raise funds of about 8% in the total expenditure, leaving the largest financing gap among all the

less developed provinces. Under such a property rights structure, the major funding should be provided by the central government treasury. According to the Planning Outline for Alternatives to Fuelwood Energy in TAR, the total investment is about 5.811 billion yuan, mainly including the biogas construction in rural areas, the power grid construction, the small hydropower stations, and the project of solar energy popularization. The central government provides more than 80% of the total investment, and the remaining funding is raised by the local government and enterprises.

The mechanism of the central government's transfer payment and partner assistance should be established. The contradiction between the needs of energy development in the farming and pastoral areas of Tibet and its insufficient financial resources will exist for a long time, and it cannot be solved without the support of the central government and developed regions. In the transfer payment, the central government raises the scale of fund allocation. During the "12th Five-Year Plan" period (2011–2015), the annual incremental revenue will be mainly provided for Tibet and other western regions. Besides, for the special transfer payment system for Tibet, the coordination between the central government's special transfer payments and the provincial supports should be strengthened, on the basis of the experience of assistance to various regions of Tibet by mainland provinces and municipalities, coordinated and implemented by the central government. Since 1973, under the guiding principle of helping Tibet to accelerate development and narrow the gap, the central government has implemented a series of preferential policies, offered a large number of financial subsidies, special subsidies and key projects construction investment for Tibet, and organized ministries and developed provinces and municipalities to provide partner assistances for Tibet in human resources, material resources, financial resources, and technologies. For example, in 1994, the central government appointed 13 ministries and commissions, and financial institutions under the State Council, 29 provinces, municipalities, and autonomous regions to jointly provide assistance to the 62 key construction projects needed for the economic and social development of Tibet. These projects cover energy, transportation, telecommunication, agriculture, animal husbandry, forestry, water, grain and oil processing, and social development, with the actual total investment of 4.958 billion yuan, in which the investment of the provinces and municipalities is about 800 million yuan. By the end of 2007, over 30 provinces, municipalities, and central enterprises and over 50 central government ministries and commissions selected and sent altogether more than 3800 cadres to assist and work in Tibet, with the assistance funds for Tibet reaching 9.668 billion yuan [26].

Ecological relocation and poverty alleviation should be combined. Ecological relocation refers to the relocation due to poor ecological environment and the difficulty for human beings to survive. The ecological conditions in many areas of Tibet comply with the standards of ecological relocation. To ensure Tibet's sustainable development under the fragile ecology, the implementation of ecological relocation in some regions of Tibet under adverse ecology is not only consistent with the Scientific Outlook on Development and the requirement of building a harmonious society, but also useful to thoroughly solve the electricity problem for the living and production of farmers and herdsmen in Tibet. There are still farmers and herdsmen in Tibet, living below the absolute poverty line. Tibet has accumulated some experience in poverty alleviation and relocation, which can be combined with ecological relocation.

6.2. Innovation of investment mechanism

In terms of the investment mechanism, the energy construction in Tibet's farming and pastoral areas is to achieve two main objectives: one is to solve the use of electricity and energy in the daily life of the farmers and herdsmen without power in order to eliminate energy poverty, achieve the energy fairness, and let the farmers and herdsmen enjoy modern civilization earlier; another one is to provide the energy needed for Tibet's rural economic development and urbanization. To achieve these objectives, policy support and capital investment is crucial. Based on the implementation experience of technology promotion and project construction of renewable energy carried out in Tibet by the government over the years, and based on the feasibility in reality, there are following four options of investment patterns to achieve Tibet's rural development goals of modern energy.

(1) The infrastructure construction mode with all the investment by government, which has been adopted by the already implemented project of "making electricity available to the countryside". Its characteristics are the following. All the construction funds are provided by the government, the implementation speed is fast, and the performance and implementation effects are obvious. However, there must be adequate funds to ensure the complete solution of the power supply for the population without electricity in a short term, and the needed investment by the government is substantial. Besides, the burden of long-term management is heavy after the project construction. There is a need for more specific implementation details on the issues of household systems, product distribution, the definition of property rights, and long-term maintenance services.
(2) The mode of government subsidies plus administrative promotion, in which the government provides subsidies for users through quota or fixed proportions and the enterprises organized or authorized by government at all levels are responsible for implementation. "Brightness Program", local anti-poverty projects, and the construction of electrification counties which are already implemented have all adopted this approach. This method is relatively robust and quick, but it is hard to achieve the optimization of resource allocation.
(3) The market promoting mode under government guidance, which is similar to the mode adopted by the China Renewable Energy Development Project (REDP) implemented by the National Development and Reform Commission, the World Bank, and Global Environment Facility. By providing merchandising allowances for enterprises instead of the direct subsidies to users, establishing the grants for technical progresses, setting up market development fund, and other means, this project gives support to the renewable energy companies' operating activities of marketization and commercialization, supports institutional capacity building, establishes consumer protection mechanism, creates a market environment, encourages fair market competition, helps enterprises to gradually reduce production costs, raises product quality, increases marketing sales, and improves after-sale services. By providing sustainable energy and power supply for users in remote areas through market operation step by step, the funds burden for the government will become light, and the development will be more sustainable. But because of the restriction of users' purchasing power and other elements, it will take a long time to achieve the electricity goal, and the market barriers need to be eliminated gradually.
(4) The market operating mode under government subsidies and supervision. According to the current situation, experience and development direction of China's renewable energy market, the market mechanism should be made to play a greater role as far as possible by making use of the current advantages. Enterprises should be encouraged to invest in the energy construction of Tibet, and the government should offer subsidies and support to the enterprises through preferential policies and incentives. For example, the mechanisms similar to "Wind Concession"

can promote the sustainable development in renewable energy industry.

7. Concluding remarks

Tibetan industry accounts for a very small proportion in national economy, and its development is relatively backward. The lack of energy condition and public services are the bottleneck holding back the economic and social development in Tibetan rural areas. Energy plays a very vital role in the basic life, production and exchange of farmers and herdsmen, and it is of special significance to them. China's government has taken various measures to greatly improve the energy input and condition of consumption in the rural areas of Tibet. Whereas, the energy development in Tibetan rural areas is relatively backward, with over 30% administrative villages without power, and the level of energy consumption is low. There are abundant reserves of hydropower, geothermal, and solar energy in Tibet. As the technology continues to develop, the cost of utilizing solar energy, geothermal power and other new energy will continue to reduce. It is the inevitable choice for Tibet's sustainable energy development to utilize Tibet's exclusive renewable energy resources in various means, finally solve the electricity shortage in Tibetan rural areas, and implement the coordinated progress of social effects, economic effects, and ecological environment. For this purpose, governmental responsibilities should be specified, the mechanism for universal services of energy should be established, and the central government's transfer payment and partner assistance should be added. Besides, financial support and favorable tax treatment should be increased, support for enterprises' innovation should be given, and the "invisible hand" should be used to guide and bring along the development of renewable energy.

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